ROAD MORTALITY IN EUROPE

– How Sensitive Is It to Demographic Structure and Population Dynamics? –

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This paper investigates the influence of demographic structure on the level of road safety as measured by mortality rates in 23 European countries and their regions. Standardised mortality ratios (SMRs) for IRTAD age-gender groups computed from fatality counts recorded in 2002 were compared with crude mortality ratios. This analysis shows that the SMRs differ only slightly from crude mortality ratios: the difference between the two varies from −4.3% to 2.8% for countries as a whole, but it is sometimes higher for regions within a single country (e.g. in Greece it ranges from −2.3% to 10.8%), suggesting that demographic structure could be omitted in international comparisons but not always in regional ones. The demographic structure explains up to 12% of regional heterogeneities in terms of road mortality in some countries. Furthermore, the development of the number of expected road fatalities was estimated for three demographic structure scenarios for the years 2020, 2035 and 2050. The aging of the population alone will not result in significant changes in the expected number of fatalities in Europe, but the impact of population aging on expected road mortality in particular countries could be high.

Key Words: Road mortality, NUTS, SMR, Population aging, Demographic structure

1. INTRODUCTION

Road safety practitioners and researchers have traditionally evaluated the road safety performance of a country by comparing its road safety risk indicators with those of other countries and by the analysis of their development in time. In an international context, three (different) risk indicators are used[1]. These indicators are the ratios between the number of persons killed in road traffic (nominator) and their exposure to traffic risk (denominator). The most commonly used denominator - and the one preferred by the health sector - is the population count. This risk indicator is considered to be a measure of mortality, the mortality rate. It reflects the degree to which road accidents affect the safety and health of the population. The number of road fatalities divided by the number of registered motor vehicles is the second most commonly used indicator of road safety, corresponding to the degree of traffic safety. Finally, the most reliable indicator, fatality risk, uses the exposure to risk expressed as the number of kilometres travelled by motorised traffic (traffic volume) as a denominator (see, for example: Kopits[2], Lassarre[3]). The extent to which these three indicators are used in international comparisons and national time-series analysis depends on the availability of exposure data. It is generally understood that in any road safety analysis at least two of these indicators should be used simultaneously to prevent the wrong conclusions being drawn about a country's road safety status. In this exploratory paper, the mortality rate, originally being a measure of personal safety is used to evaluate the level of safety in road traffic. (As a reminder, this indicator does not reflect the exposure of the population to risk in road traffic, since it is not related to the level of motorisation of a country and other road traffic determining characteristics.)

The mortality risk faced by people in road traffic is not equal for men and women, and the degree of risk also varies significantly with age[4-7]. The difference in risk for men and women is thought to be a result of various behavioural and physiological aspects related to gender and differences in their exposure in road traffic (and to a different modal-split pattern). The difference in risk for different age groups is then related, among else, to the development of driving skills over time and to the progressively greater vulnerability of the human body. For example, young men aged 18-24 have a mortality risk in road traffic that is three times higher than that of other road users. The elderly are more vulnerable to trauma than other groups, as shown by McCoy[8] and Evans[5]. The latter found that the fatality risk from the same physical impact is (28±3)% greater for females than for males, and increases with age from 20 onwards at compound annual rates of (2.52±0.08)% for males and (2.16 ±0.10)% for females[5].

There are not only substantial differences in demographic structure from one European country to another, but also significant demographic differences between regions in each country. These differences are attributable to a variety of factors. For example, the fertility rate in most Central and Eastern European countries has been very low since the early 1990s, and life expectancy in these countries is some 10 years less than in Western European countries[9-11]. These demographic differences among European countries are mostly due to differences in the economic, sociological and political conditions that determine longevity and quality of life. The demographic differences between regions of the same country usually reflect the migration of some groups of the population from poor, scarcely populated regions to highly urbanized regions, and vice-versa due to different economic potential of regions.

Demographic differences do not relate solely to the age distribution of the population, but also to the relative numbers of men and women. Since the life expectancy of men is significantly lower than that of women[12], and since men are more likely to die prematurely, the elderly population is characterised by some specific structural differences. Demographic differences between 25 European countries are shown in Figure 1, which gives a percentage breakdown of each country's population by age and gender in 2002. Besides the reference value of EU25 (corresponding to the percentage share of a country's population in each age/gender group in relation to the total population of the 25 European countries), it shows the values for the countries with the minimum and maximum percentages of population in particular groups, giving an idea of the variations between countries.

At the national level, data on the age and gender of road accident victims are available in all European countries (although the proportion of those with unknown gender-age characteristics can be appreciable in some countries). For practical reasons, however, it is usual to work with age bands, as it leads to higher counts having statistically higher value in different comparisons. For the purposes of this paper, the IRTAD (International Road Traffic Accidents Database) age groups were taken, which allowed easy access to national data. It can be assumed that the aggregation used in the IRTAD database results in relatively minor differences in risk within particular age/gender groups, since the age groups are designed in such a way as to take account of all the major differences between ages in respect to risk, being related to the differences in traffic mode use (national legislation setting).

Beside the differences discussed above, one should not forget demographic shifts over time. From a demographic point of view, Europe's population structure is changing rapidly due to the aging of its population[10]. There are three different factors behind the aging of the population: the decline in fertility rates, the increase in life expectancy and the maturing of the baby-boom generation. Population aging affects society as a whole and has repercussions on all generations. According to the Eurostat baseline scenario for population changes, the total population in the age group 15-24 years will fall by 25% between 2004 and 2050, while the elderly population (65-79 years-old) is expected to increase by 44%. As for very elderly people, those aged over 80 years, their

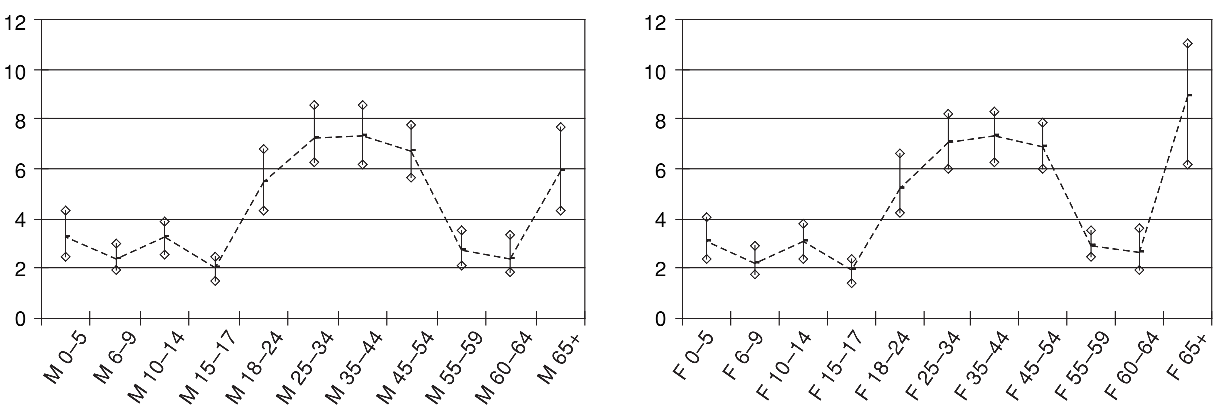

Fig. 1 Population distribution (as percentage of group in total population) by age/gender groups (M = male, F = female)

number will soar by 180%[10].

The questions to be answered in this paper are: How do demographic differences influence the level of mortality risk and how will changes in population structure affect road fatality records in the future?

2. METHODOLOGY

Epidemiologists are often faced with the need to compare mortality rates in different geographic areas. Indirect standardisation, producing a 'standardised mortality ratio' (SMR), is the most commonly used technique for doing this. Standardisation is necessary when comparing several populations that differ with respect to age (and/or gender), because age and gender have such a powerful influence on health risk. Despite the recent evidence of some epidemiological studies that such indirect standardisation is inappropriate for small area comparisons (not necessarily in terms of area, or population size), since SMRs for different geographic areas have different denominators[13], this is not a major obstacle for an analysis that includes regions, because fairly similar geographic units are used in this paper.

The analyses contained in this paper relate to the three levels of spatial aggregation: the country level, and two regional levels corresponding to NUTS-1 and NUTS-2. The NUTS (Nomenclature of Statistical Territorial Units) refers to the official Eurostat regional classification. The NUTS classification is hierarchical and subdivides each country (NUTS-0) into NUTS-1 territorial units, each of which is subdivided into NUTS-2 territorial units and so on, whereas some territorial units are classified at several different NUTS levels.

The source of demographic data for this analysis is the Eurostat - Regio database, containing the annual average population counts for 25 European countries in adopted age-gender groups. Furthermore, the same type of data for regions, corresponding to the NUTS-2 disaggregation level, was obtained for 23 countries. (Annual average population data in particular age-gender groups were not available for Slovakia and the United Kingdom). The source of data on disaggregated national road fatalities is the IRTAD database, which contains fatality counts in age-gender groups for 13 EU countries (Austria, Belgium, Czech Republic, Denmark, Germany, Spain, Finland, Hungary, France, Ireland, Poland, Slovenia, United Kingdom). As regards the absence of the other 12 countries, that is due in some cases to their absence from the IRTAD database and in others to the poor design or unreliability of their accident reporting systems. For example, in some countries the proportion of road fatalities with unknown age/gender remains quite significant and it is inappropriate therefore to use it for accurate analyses. Aggregated fatality counts for other countries come from the CARE database. All road fatality counts are police-reported official data adjusted for the official 30-day fatality definition (immediate fatalities and those occurring within 30 days of the accident). The mortality rates (M_i – number of road fatalities per 100,000 population) were calculated as the number of fatalities in each age/gender group per hundred thousand inhabitants in the same group.† As a common standard, mortality rates by gender/age group in 13 EU countries multiplied by a scaling coefficient π were used. The scaling coefficient π was obtained by dividing the mortality rate of 25 European countries in 2002 (M_{EU25} = 50,089/4,539.77) by the mortality rate in 13 European countries (M_{13EU} = 35,939/3,362.92) for which detailed data are available. The scaling coefficient was calculated as π = 11.032/10.687 = 1.032 and applied to each age/gender group analysed. Since the 13 European countries accounted for 35,941 of the 55,089 road fatalities recorded in all EU25 countries in 2002 (71% of the total) and were geographically and demographically representative of the EU25 countries, the mortality rates by age/gender group arrived at in this way can be considered valid for the EU25.

The road mortality ratio of each spatial unit (country, region) is calculated separately by dividing the mortality rate of the unit by the average mortality rate of the 25 European countries in 2002. ($MR_i = M_i/11.033$)

The following formula is then used to calculate the *SMR* of a particular geographical unit (country, region):

$$SMR_i = \frac{Y_i}{Y_i^*} \quad (1)$$

where:

Y_i is the observed number of fatalities in the unit i,

Y_i^* is the expected number of fatalities in the same unit i,

$$Y_i^* = \sum_{jk} \tau_{jk} \cdot N_{ijk} \quad (2)$$

where:

$\tau_{jk,}$ is the standardised mortality rate of the age-sex group j,k,

N_{ijk} is the population count of this group in the geographical unit i,

† Note that, unlike in epidemiology studies, road fatalities are classified by the place where the accident occurred and not by the place of residence of the accident victims.

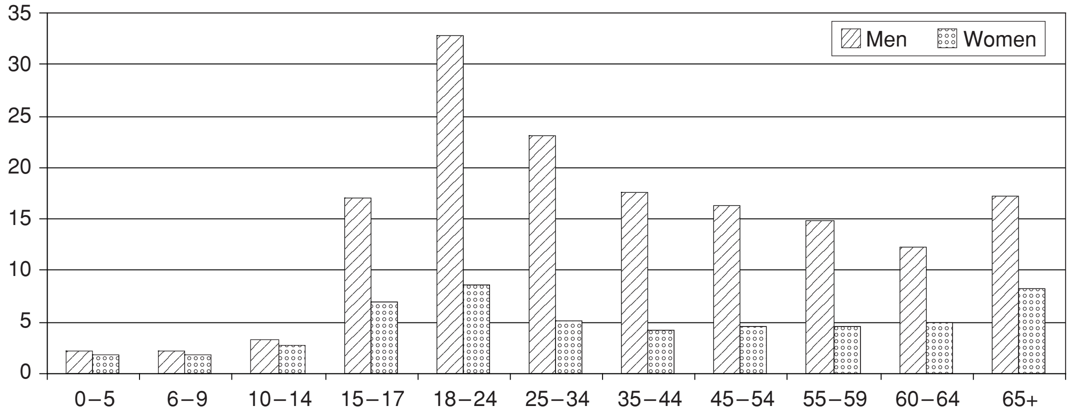

Fig. 2 Standardized mortality rate (τ_{jk}) by age/gender groups adjusted for EU25 countries (in 2002 per 100,000 inhabitants)

The effect of standardisation can then be expressed as follows:

$$E_i = \frac{SMR_i}{MR_i} \quad (3)$$

or as a percentage change:

$$F_i = \frac{SMR_i - MR_i}{MR_i} \cdot 100\,\% \quad (4)$$

where:

SMR_i is the standardised mortality ratio of the unit i,
MR_i is the mortality ratio of the unit i.

The average EU25 mortality rate by age/gender group is shown in Figure 2. This was obtained by multiplying the mortality rate of 13 European countries by age/gender group by the scaling coefficient π. There is a small difference between the mortality rate of men and women in the first three age groups, but in the case of 15-17-year-olds the rate for men is twice as high as in age groups 18-24 years and 35-44 years, and up to three times higher for men than for women. As regards the over-60 years, the mortality rate for men is only double that for women. It has to be pointed out here that if the exposure of a particular age/gender group to risk on the road is taken as a denominator, then for any particular group the women likely run a lower risk in traffic in comparison with men.

Since the fatality risk and the proportion of population in particular age/gender groups vary, one can be interested which population group change will result in the most significant change of expected fatalities in Europe. This is illustrated in Figure 3, presenting the percentage change in the expected number of fatalities in 23 EU countries due to a 10% change in the number of inhabitants in particular age/gender groups. The population change in wide age groups having higher relative number of population (see also Figure 1 and Figure 2) results in the highest change in expected mortality.

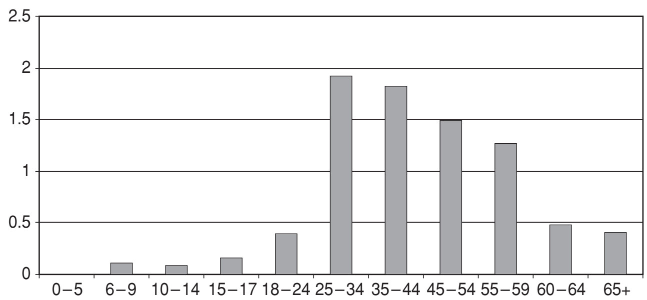

Fig. 3 Percentage change of expected number of fatalities due to 10% change of population in age groups in Europe

The demography can be considered as an explanatory factor when analysing the number of road fatalities in a given spatial unit. To assess its ability to account for the differences in road mortality in countries and regions, the following two models can be considered:

$$E(Y_i) = N_i \cdot \lambda \quad (5)$$

$$E(Y_i) = N_i \cdot \lambda \cdot D_i \quad (6)$$

Where Y_i is the registered number of fatalities in unit i, N_i is the number of inhabitants in this unit, λ is the average level of road risk in 25 EU countries and D_i is the variable standing for the role of demographic structure. Given that these are multiplicative formulae, multiplicative residuals stand for the difference between the local unit risk level and the average one (λ).

$MR_i = Y_i / E(Y_i)$ ....(7)

By computing SMR_i, the variable D_i is taken into account. Since all other variables in the model do not change, the variance difference obtained by comparing Y_i/N_i and λ with Y_i/N_iD_i and λ shows which proportion of heterogeneity is due to the different demography. This can be simply computed as follows:

$\psi = [\sigma^2(MR_i) - \sigma^2(SMR_i)] / \sigma^2(SMR_i)$ ....(8)

A positive value of the coefficient ψ indicates a decrease of variance between the mortality ratios (MR_i) and standardized mortality ratios (SMR_i), meaning that the demography accounts for the variations in road mortality between considered countries (regions) to the extent expressed by the value of the coefficient ψ.

Choropleth maps provide an easy and effective way of visualising how measurements vary across a geographic area, and they also enable areas with extreme values to be identified. For the purposes of this paper, the SMR and the rate between the SMR and the MR at NUTS-2 level were mapped. The limits of the five classes applied were identified by the natural breaks classification technique. The natural breaks classification method (also known variously as optimal breaks and the Jenks' Method) identifies breakpoints by looking for groupings and patterns inherent in the data.

3. RESULTS

As mentioned above, the effect of standardisation on mortality rates is expressed here by comparing the SMR_i with the MR_i. The SMR_i stands here for the difference between the road mortality experience of the population and the experience it would have if it experienced the age and gender specific rates of the comparison population (rate between the number of observed fatalities and those expected in 25 European countries). An SMR greater than 1.0 indicates that more fatalities have occurred than would have been expected; while a ratio of less than 1.0 indicates that fewer fatalities occurred. The decimal fraction shows the percentage comparison. SMR values for the NUTS-2 regions are mapped in Figure 3, showing the heterogeneity of mortality ratios across Europe.

For this paper, the effect of standardisation on the mortality rate was assessed through the ratio $E_i = SMR_i / MR_i$. A value greater than 1 means that the standardised mortality ratio is higher than the mortality ratio, leading to the conclusion that the population structure of the country in question has a favourable effect on the mortality rate (leading to a higher SMR), and vice versa. For example, in Western European countries a relatively low proportion of the population is in the most risky age groups, resulting in a relatively high SMR (and $E>1$), while Southern European countries have a relatively "unfavourable" population structure with respect to road traffic risk, resulting in higher expected fatality counts and a lower SMR ($E<1$).

Figure 5 ranks countries according to the value of the ratio E_i, indicating the percentage difference between the standardised mortality ratio SMR_i and the mortality ratio MR_i for each country. Note that this ranking contains only 23 European countries, since the average annual population counts for the United Kingdom and Slovakia were not available for this analysis. Moreover, this has little influence on countries' road mortality rankings, resulting only in a few countries swapping positions (Portugal with Estonia, Hungary with Luxemburg, and France with Estonia).

The variance between the SMR_i and MR_i has been analyzed for 151 NUTS-1 and 208 NUTS-2 regions in 23 European countries. One (five) NUTS-1 (NUTS-2) French overseas regions were withdrawn due to their outlying location and different demographic conditions. The variance of E_i for all 23 European countries is $4.063 \cdot 10^{-4}$. The variance of the ratio E_i grows with spatial aggrega-

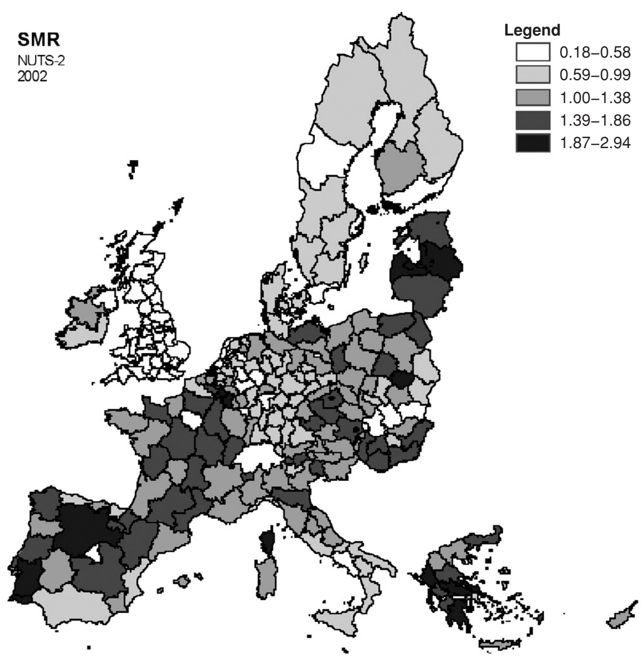

Fig. 4 Standardised mortality ratio (SMR) in NUTS-2 regions of 23 EU countries

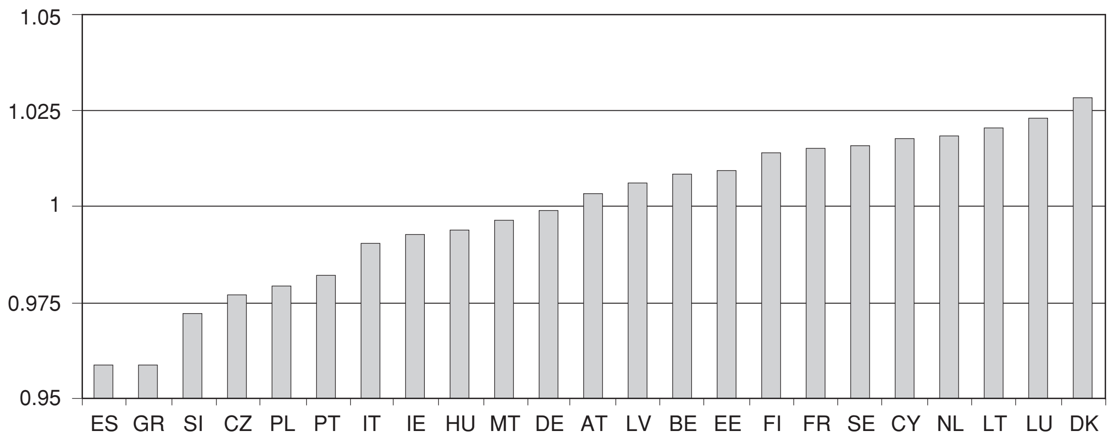

Fig. 5 Ranking countries according to the influence of population structure on mortality rate ($E_i = SMR_i/MR_i$)

tion, but at NUTS-1 level it is bigger than at NUTS-2 level. The variance of the ratio E_i at NUTS-2 level is smallest for the Czech Republic ($9.25{\cdot}10^{-6}$), Poland ($25.77{\cdot}10^{-6}$) and Sweden ($67.05{\cdot}10^{-6}$), and highest for Greece ($3.46{\cdot}10^{-4}$), Germany ($5.29{\cdot}10^{-4}$) and France ($9.33{\cdot}10^{-4}$). The average infra-national variance of E_i for the countries, $2.17{\cdot}10^{-4}$, is lower than the intra-national variance of 23 countries. Regional variations are thus smaller than the intra-national ones. Table 1 presents the variance between all 23 countries and 151 (208) regions.

Table 1 The variance between SMR_i/MR_i values at the three levels of spatial disaggregation

	Countries	Regions (NUTS-1)	Regions (NUTS-2)
N	23	151	208
σ^2(E)	$4.063{\cdot}10^{-4}$	$12.56{\cdot}10^{-4}$	$5.869{\cdot}10^{-4}$

The effect of the population structure on the observed road mortality can be captured at several levels of spatial disaggregation. Figure 6 shows the heterogeneity of SMR/MR values across Europe, while Figure 7 shows the variance of the SMR/MR rate in 15 countries. Again, the maximum and minimum values for NUTS-2 regions are presented around the national value (NUTS-0 level). Eight of the 10 European countries missing from this figure do not have NUTS-2 regions, while detailed population data are not available at NUTS-2 level for the other two (United Kingdom, Slovakia). The countries are ranked according to the relative difference of E values: $\lambda = (E_{max} - E_{min})/E_{country}$. The two limits show the extreme values for the countries and create a range of variations of 5 among countries. This is generally narrower than the range of variation of E values among NUTS-2 regions. The observed variations are directly related to the demographic structure of regions: densely populated regions (with a higher GDP) usually have a higher share of young, economically active population with an increased mortality risk in road traffic compared to regions with low population density.

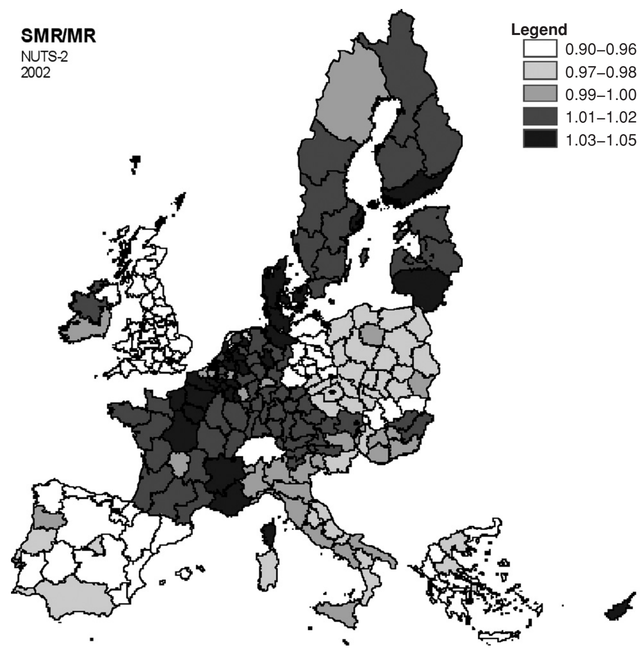

Fig. 6 Rate between SMR and MR for EU countries for NUTS-2 regions

Now let us compare two different SMR_i values, one standardised by age and gender and the other one standardised by age only. The difference between these two

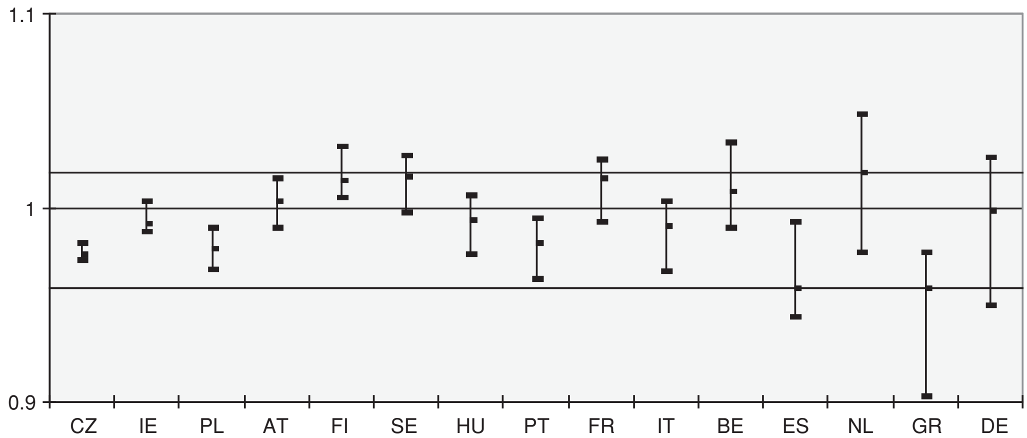

Fig. 7 Rate between SMR and MR for EU countries at NUTS-2 level in 2002, minimum, maximum values at NUTS-2 level around the value for country level

ratios (*F*) varies from –1.0% to 2.5%, whereas the average absolute change is about 0.7%. The standard deviation for country level values ranges from 0.0003 to 0.04 and is lowest for Italy, Ireland and the Czech Republic and highest for the three Baltic countries. These differences are relatively small and would not significantly influence presented conclusions.

After drawing some conclusions about the influence of structural demographic differences in populations on the level of road safety as measured by the mortality ratio and SMRs, one may want to look at how future changes in population structure will influence expected road safety records. In the following exercise, expected fatality counts are calculated for the national demographic patterns of 23 EU countries. The latest demographic forecasts published by Eurostat provide the data needed to calculate expected fatality counts for the three years 2020, 2035 and 2050. As we are seeking to analyse the structural changes in population (percentage distribution in each age/sexgender group) only, changes in the total population were not taken into account. Using road mortality rates as calculated above for age/gender groups in 2002, the expected number of fatalities can be calculated for the three years. The expected number of fatalities for each year is then divided by the expected number of fatalities for 2002, so the ratio between the two years is obtained. This ratio shows whether the demographic changes will result in a rise or a fall in the number of road fatalities.

For all 23 EU countries, the expected number of fatalities decreases from 43,201 in 2002 to 41,856 in 2020, but then rises to 42,498 in 2035 and 42,730 in 2050. But for some other countries, the changes are more significant, as shown in Figure 8: For example, in Spain the expected number of road fatalities falls from 4,754 in 2002 to 4,418 in 2020 and then rises to 4,576 in 2035 and 4,595 in 2050 respectively. In other words, the number is 7.6% smaller in 2020, but 3.5% (0.4%) higher in 2035 (2050). Spain, Greece, Latvia and Denmark are the countries whose expected mortality is most sensitive to structural demographic changes, while in the Netherlands, Cyprus and Latvia expected mortality rates are stable over the time.

Last, but not least, the statistical evidence on the role of demography as an explanatory factor for various fatality records was studied. The value of the variance between mortality ratios (MR_i) and standardized mortality ratios (SMR_i) of countries and regions within particular countries are summarized in Table 2 and Table 3. The statistical significance of the difference between the variance of the two ratios can be assessed by the so called F-concept[16]. The significance at the 95% level is reached if the rate of the two ratios (F_0) is smaller than the F critical value, which depends on the degrees of freedom in the numerator variance (a-1) and in the denominator variance [a(n-1)].

While there is no evidence of the explanatory effect of the demography at a country level (NUTS-0), the figures suggest that demography explains 10%, respectively 5% of the variation in road mortality between 141 NUTS-1 (208 NUTS-2) regions of 23 EU countries, but the estimates is no significant at NUTS-3 level.

Similarly, the demography accounts for up to 10% of the variance in road mortality registered within NUTS-2 regions of some EU countries, but estimates are not significant.

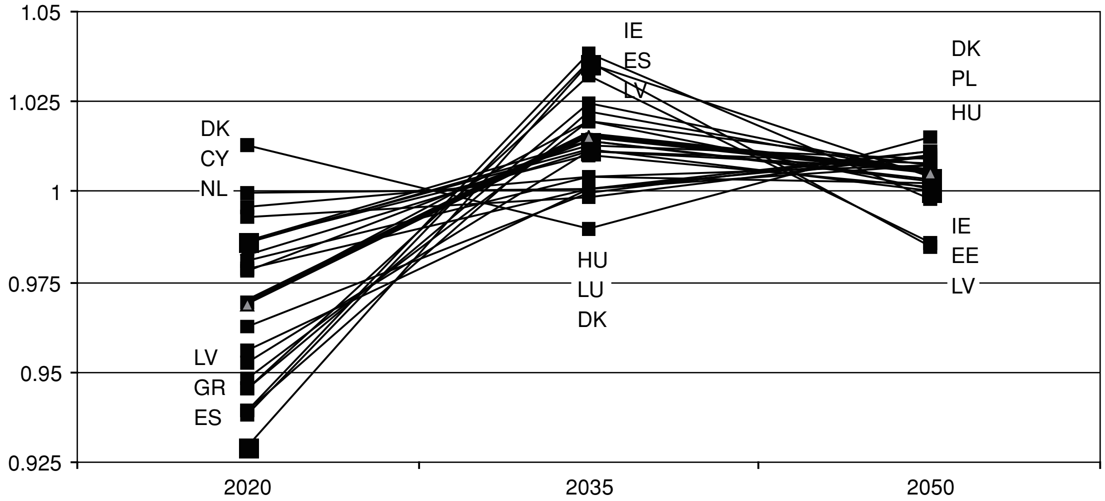

Fig. 8 Ratio between the expected number of road fatalities in 2020 (2035, 2050) and 2002 in 23 EU countries

Table 2 The variance of MR and SMR at the three levels of spatial disaggregation

σ^2	Nr	MR	SMR	F_0=MR/SMR	ψ	DF	F_{crit}(95%)	Sign. (95%)
NUTS-0	23	0.168	0.168	1.000	0.000	22	2.12	-
NUTS-1	151	0.207	0.185	1.119	11.892	150	1.10	**
NUTS-2	208	0.239	0.226	1.058	5.752	207	1.10	-

Table 3 The variance of MR and SMR at regional level (NUTS-2)

σ^2	Nr	MR	SMR	F_0=MR/SMR	ψ	DF	F_{crit}(95%)	Sign.(95%)
BE	11	0.332	0.350	0.948	-5.202	10	2.98	-
CZ	8	0.101	0.096	1.056	5.598	7	3.73	-
DE	42	0.102	0.097	1.046	4.565	41	1.69	-
GR	13	0.271	0.248	1.093	9.307	12	2.75	-
ES	19	0.241	0.214	1.126	12.623	18	2.12	-
FR	22	0.104	0.106	0.981	-1.879	21	2.12	-
IT	21	0.121	0.119	1.022	2.225	20	2.12	-
HU	8	0.066	0.063	1.047	4.694	7	3.73	-
NL	12	0.033	0.034	0.978	-2.246	11	2.75	-
AT	9	0.138	0.141	0.983	-1.653	8	3.44	-
PL	16	0.110	0.105	1.047	4.684	15	2.49	-
PT	7	0.598	0.539	1.110	11.047	6	4.28	-
FI	5	0.106	0.104	1.012	1.171	4	6.39	-
SE	8	0.036	0.036	1.017	1.708	7	3.73	-

4. CONCLUSIONS

The differing demographic structures of 25 European countries have only a minor influence on road mortality rates (ratios). Differences in the mortality ratio and the SMR between countries vary only slightly, from −4.3 to 2.9%. However, the corresponding ratios calculated for the NUTS-2 regions of the same countries show greater variations, the largest ones being found in France, Germany, Greece and the Netherlands, which are countries with a high number of NUTS-2 regions in general. But the variations are relatively small in the case of small countries such as the Czech Republic and Hungary. (In Greece, for example, the ratios vary from −2.3% to −10.8 %, while in the Czech Republic they vary only from −1.9% to −2.8%).

The interpretation of the SMR has to take full account of the possible effects of random variations due to the low number of fatalities in some of the age/gender groups used, especially in the case of small geographical units. The limitations of the approach outlined here are due to the use of a relatively small number of age/gender groups and 12-month data, while forecasting the SMR also suffers from the absence of a more complex prediction model that enables the number of road fatalities to be estimated. A further disaggregation of some age groups, especially the relatively wide ones (18-24, 65+), is very likely to result in minor changes in computed SMR_i, and hence slightly different conclusions.

Forecasting how the (relative) mortality risk in traffic will develop for particular age groups is a very complex business, since it depends so heavily on how these groups perform in traffic and on other factors[14]. An increased proportion of elderly drivers in traffic will result in an increased number of fatalities among them, but it will not be as great[15]. This leads to the conclusion that linear predictions of older drivers' accident involvement that is directly based on their increasing numbers are likely to be overly pessimistic. Greater longevity will bring a significant increase in the number of very old drivers who are at greater risk of being involved in road accidents[14]. As the size of this age group is set to double between now and the year 2050, when it is expected to represent about 30% of the total population in Europe[12], there is a strong need to determine the road risk faced by several age groups above this age. Road safety administrators are likely to target the elderly more closely in their statistics, and road safety researchers should make a contribution to a better understanding of the risk faced by the elderly.

The aging of the population, together with changes in total population, will result in relatively minor changes in the expected number of road fatalities in Europe, but aging could have a major impact in some countries, since there might be a shift in the SMR_i calculated by country, with values by 2050 showing differences of ±30% relative to those calculated for the year 2002.

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